EXPERIMENTAL DATA ON CASCADE MULTIPLICATION OF ELECTRONS IN LEAD

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Experimental data have been obtained on the number of secondary electrons at the depth of 1.4, 2.8, and 4.2 radiation units in lead for primary electron energies of 200 — 500 Mev. A comparison is made with theoretical calculations carried out by the Monte Carlo method.

1. INTRODUCTION

A large number[1,2]* of theoretical studies has been devoted to the passage of electrons through matter and particularly to the calculation of the so-called cascade curves. In recent years, an advancement in the methods of computation was accompanied by a further improvement of the cascade curves due to a more accurate account of the ionization losses of electrons and of their scattering, and of the energy dependence of the photon absorption coefficient. Many other important aspects, however, remain obscure or are known only to a crude degree of approximation. These comprise fluctuations of the number of particles, angular and lateral distributions, etc.

It should be noted that, apart from its intrinsic interest, the problem is of great value for various applications. The study of the cascade multiplication of secondary photons, for instance, makes it possible to determine the energy of π^0 mesons produced in nuclear interactions. Another example is supplied by the application of the cascade theory to energy measurements of γ-rays emitted in the decay of unstable particles (e.g. K mesons). We do not have to stress the widely recognized importance of the cascade theory for the general picture of cosmic radiation.

In the present work we deal with the electron cascade multiplication in a dense material, namely lead. It is our aim to compare experimental data on cascade multiplication of electrons in lead with the cascade theory.

2. EXPERIMENTAL PART

The study of electron cascade multiplication was carried out by means of a multiplate cloud chamber combined with the magnetic spectrometer of Alikhanian and Alikhanov.[3,4] The momentum of primary electrons was determined from the curvature of the trajectory in the magnetic field by means of a counter hodoscope placed in the field. Data concerning the accuracy of momentum measurement of a single particle are given in the table.

Electron momentum $p \cdot 10^8$ ev/c	$(\Delta p/p)_{prob}$, %
2.0	1.3
3.0	2.0
4.0	2.6
5.0	3.3

Electron multiplication was observed in a large rectangular cloud chamber (650 × 280 × 180 mm) placed below the hodoscope array. The chamber contained seven lead plates, 7 mm thick. The top of the chamber consisted of 8 mm Al and 2 mm Cu. The tracks were photographed with a stereoscopic camera.

The conditions of the experiment made it possible to identify electrons without any difficulty. The momentum of primary electrons was determined in every case and secondary electrons under the first, second, and third lead plates were counted in the cloud chamber pictures. The most appropriate procedure, evidently, was to compare the results with the cascade curves obtained by Wilson[5] by means of the Monte Carlo method. The reason for this, as correctly observed by Wilson,[5] is that a marked background due to stray slow electrons is usually present in cloud chamber pictures. These electrons could be erroneously identified as slow electrons of the shower, which, in general, propagate at

*For additional bibliography cf. Refs. 1 and 2.

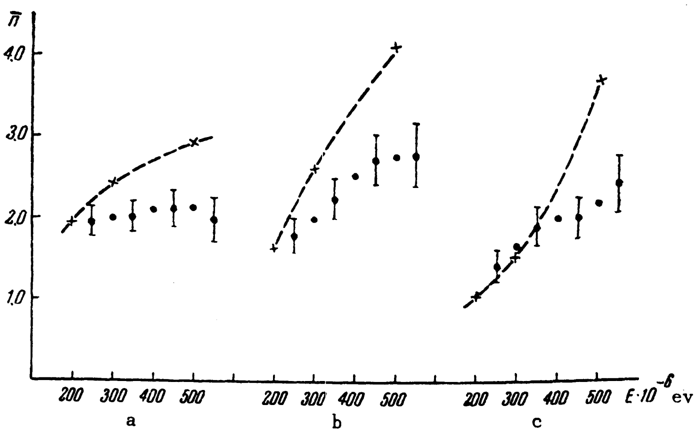

FIG. 1. a — 1.4; b — 2.8; c — 4.2 radiation units

large angles to the shower axis. For this reason Wilson introduces apart from the ordinary cascade curves [denoted in the following by (I)], another set of cascade curves (II) for comparison with cloud-chamber results. The cascade curves (II) give the mean number of electrons $\bar{n}$ at a given depth going in a relatively narrow cone of angle ± 30° to the axis. A marked background of slow electrons was observed in the present experiment, and the electrons going at an angle of ± 30 — 40° to the shower axis were therefore counted and the results compared with the curves (II).

The results are shown in Fig. 1. The x-axis represents the primary electron energy, and the y-axis — the mean number of secondary electrons at a given depth. The graphs 2a, 2b, and 2c correspond to depths of 1.4, 2.8, and 4.2 radiation units respectively.* The points in the graphs represent the experimental values of the mean number of secondary electrons at the given depths for mean primary electron energies equal to 250, 300, 350, 400, 450, 500, and 550 Mev. The width of the energy interval at each point is 100 Mev, and the intervals overlap. For example, the mean energy of 350 Mev, corresponds to the 300 — 400 Mev interval, and the mean energy of 400 Mev — to the 350 — 450 Mev interval of primary electron energy. Values obtained from Wilson's theoretical curves for the energies of 200, 300, and 500 Mev are denoted by crosses. The dashed line gives the interpolated intermediate energies.

3. DEDUCTIONS

Comparison of the experimental data with the theory shows that for the primary electron energy of ~ 200 Mev the observed number of secondary electrons at depths of 1.4, 2.8, and 4.2 radiation units approximates the values predicted according to Wilson. For large energies, the theoretical values are systematically greater than the experimental results; the difference in the mean number of particles amounts to ~ 25 — 30%. This discrepancy cannot, however, be regarded as quantitatively accurate since the experimental bias has been different from conditions represented by the curves. In particular, the theoretical curve gives the average number of particles within a solid angle while experimental data are expressed in plane angles measured in the photographs and are therefore rather low. Inclinded incidence of primary electrons, a factor increasing the effective thickness of plates, has not been taken into account. The inclination is small for electrons of $E \geq 300$ Mev and the effect is negligible.

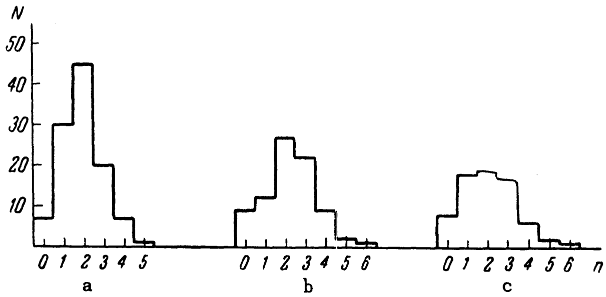

FIG. 2. a — 1.4 radiation units, $E = 250$ Mev; $N_{tot} = 110$; $\bar{n} = 1.97$; $\overline{(n - \bar{n})^2}/\bar{n} = 0.5$; b — 2.8 radiation units, $E = 350$ Mev; $N_{tot} = 82$; $\bar{n} = 2.24$; $\overline{(n - \bar{n})^2}/\bar{n} = 0.76$; c — 4.2 radiation units, $E = 450$ Mev; $N_{tot} = 71$; $\bar{n} = 2.07$; $\overline{(n - \bar{n})^2}/\bar{n} = 0.85$

The following explanation of the observed discrepancy seems very plausible: the cascade curves (I) have been obtained by Wilson from the general cascade curves by exclusion of all secondary electrons with energy $E < 8$ Mev. It has been assumed that essentially electrons with $E > 8$ Mev are present in the narrow cone close to shower axis. It is clear that such a criterion is approximate and that no great accuracy can be claimed for cascade curves (II). The cascade curves would fall lower than those shown in the graph were the limiting energy greater. It should be noted that Wilson's general cascade curves are in a good agreement with accurate calculations of Ivanenko[2] based on computation of the moments of cascade curves.

*It has been assumed, as in Ref. 5, that one radiation unit in lead equals 0.5 cm.

Two experiments on the multiplication of electrons in lead plates of a cloud chamber can be mentioned. Wilson[5] reports that the experimental results of Shapiro[6] are in a good agreement with the theory for electrons of 200 Mev. The results of a detailed study of d'Adlau[7] refer to primary electrons with mean energies of 63, 104, 170, 280, 460, and 770 Mev and do not contradict our results in the region that permits comparison with the curves of Wilson. We have not considered the experiments of Hinotani et al.[8] since an indirect method of primary electron energy determination had been used, nor that of Hazen[9] dealing mainly with electron cascades in copper.

In conclusion we shall discuss several histograms (Fig. 2) representing the fluctuations in the number of particles observed at a given depth, for a given energy of the primary particle. In Fig. 2 the x-axis represents the number of particles within the angle of ± 30° with the shower axis, and the y-axis — the corresponding number of cases. It should be noted that in some cases similar histograms for high-energy primary electrons have a wider distribution, although the statistical accuracy of the results is then considerably lower. It has been found that almost in all cases the expression $\overline{(n-\bar{n})^2}/n$ is smaller than unity, while it should equal 1 for the Poisson distribution.

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